



Decadal to centennial shoreline change illustrated by case studies from Ireland and South Africa

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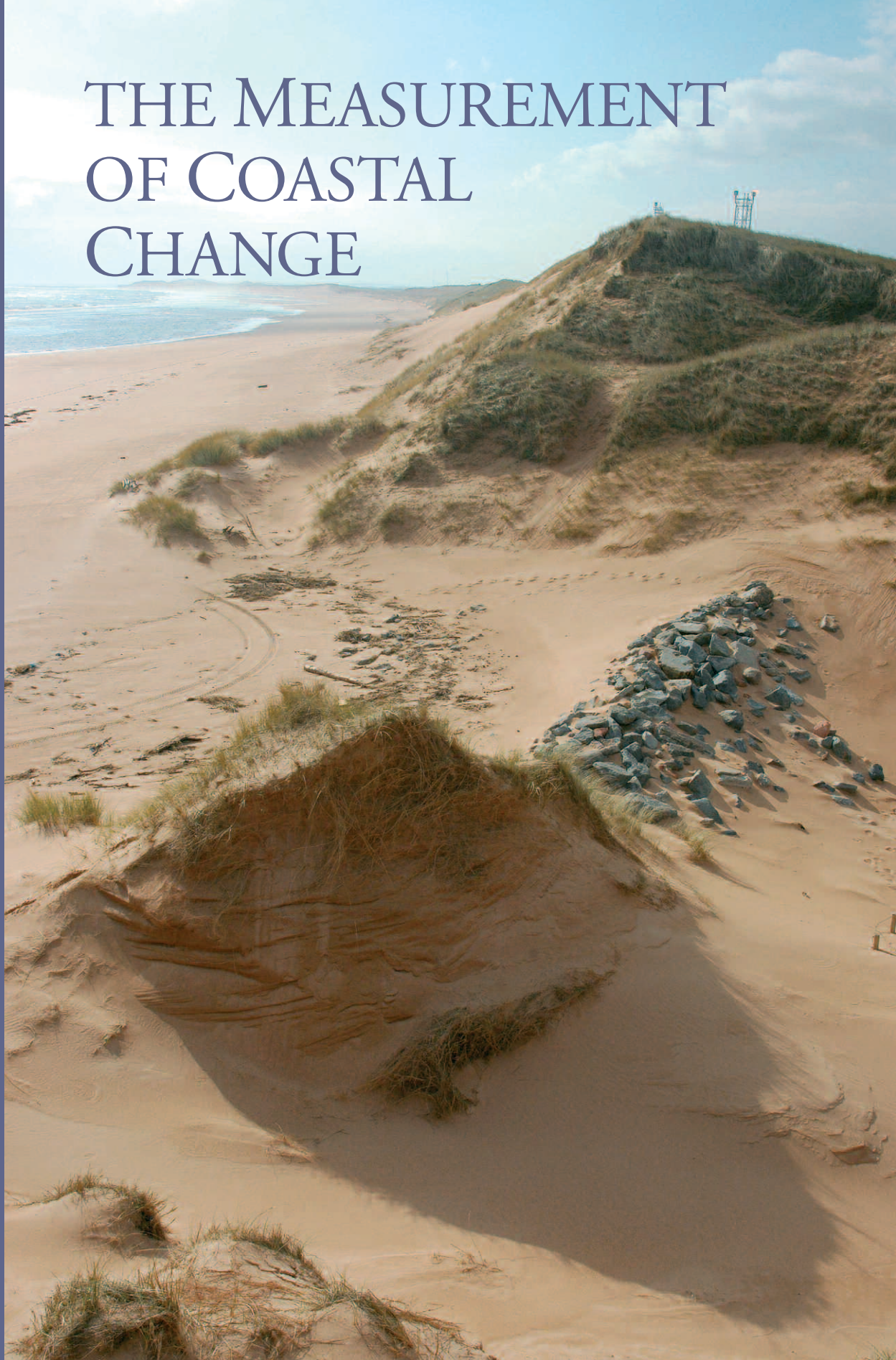
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THE MEASUREMENT OF COASTAL CHANGE



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Proceedings of ^{THE} St Fergus
Symposium

Edited by K. Pye and W. Ritchie

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Preface and Acknowledgements

In May 2007, the managers of the companies operating the St Fergus Gas Terminal agreed with the recommendation of the St Fergus Coastal Environment Committee to sponsor a technical Symposium at St Fergus. Unlike the previous conference in 1997 that produced the publication 'The St Fergus Coastal Environment', the theme was international and tightly defined on the problems associated with the measurement of coastal change. All the speakers and most of the audience gathered on an 'invitation' basis. Thus, in addition to the formal presentations, there were lively discussions throughout the sessions and during the site visits to the St Fergus beach and dunes and to a recent renourishment scheme at Aberdeen City beach.

These transactions include all the technical papers and have been edited by Professor Ken Pye and Professor William Ritchie.

The conference was organised by the staff of the Aberdeen Institute for Coastal Science and Management, notably Lynda Kingham and Elaine Ball, with the assistance of Public Relations staff from all four terminal operators, i.e. National Grid, Shell, Total and ExxonMobil.

These transactions were 'desk-top published' by Elaine Ball and printing advice was provided by Derek Kemp of the University of Aberdeen Central Printing Services.

The planning application for the development of the terminal as the location for incoming pipelines with raw gas from the North Sea, its processing and transmission from the site into the National Gas Grid was submitted in 1973. Although the size, capacity and number of facilities have expanded greatly and are still doing so, and nine pipelines now cross the beach and dunes, the essential character and nature of the coastline remains remarkably unaltered and its appearance is relatively unchanged due to assiduous restoration of the pipeline landfall cuttings through beach and dunes. Nevertheless, there continues to be constant monitoring of various elements of the natural coastal environment. Among these programmes, detection of beach and coastline changes has been significant. How this is done and the reliability of rates of change remain important elements in the management of the coastal zone – and this concern is the origin of the Proceedings of the Symposium – and as such is regarded as a useful contribution to the general evolution of techniques and methods for the detection and management of change.

DECADAL TO CENTENNIAL SHORELINE CHANGE ILLUSTRATED BY CASE STUDIES FROM IRELAND AND SOUTH AFRICA

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Abstract

The significance and relevance of shoreline change measurements depends to a large extent on the temporal and spatial scale at which they are made. For management purposes, decadal to century scale temporal changes are usually deemed most important. On most shorelines of the world, however, the record of historical change is fragmentary and of variable quality - yet it is the only record that exists. Interpretation of historical coastal behaviour requires a combined deductive and inductive approach in which all available evidence of change and potential driving forces is compiled and interpreted in the context of knowledge of coastal processes that is often derived from short-term observations or experiments. By reference to several examples in South Africa and Ireland, the approach to assessment of historical scale shoreline change is described and the importance of understanding of long-term coastal behaviour for the proper interpretation of shoreline changes is discussed.

Introduction

Shoreline changes take place at a variety of temporal and spatial scales and proper understanding of coastal behaviour requires that short-term patterns of change be placed in longer-term perspective. Changes over a tidal cycle, for example, need to be understood in terms of spring-neap variability and these in turn may be masked by seasonal effects. The cumulative effects of change at any timescale may be non-linear (e.g. Ashton et al., 2001) and the impact of high magnitude, low frequency events may also be important. For management purposes, the typical timescale of interest is in the decadal to century region. The timescale of academic research, however, usually means that field assessments are constrained to a short time period and the need for long-term monitoring and the acquisition of long-term data sets has only recently been recognised. Only in a few rare instances (e.g. Netherlands; Wijnburg and Terwindt, 1996) do long-term measurements at regular and frequent intervals exist. Records of historical shoreline change therefore are usually derived from maps and air photographs taken at long intervals and varying scale

(Dominguez et al., 2005) and for different purposes. They may also be taken at different stages of the tide and during different seasons such that their context is either unknown or must be inferred by reference to other records of, for example, tidal variation, wave or weather conditions. Consequently, research into decadal to century scale shoreline change typically relies on an incomplete, irregularly-spaced record of varying quality from which morphological changes and the reasons for them must be deduced. As Fenster and Dolan (1993, p177) note "...process/response data from most world coastlines are neither synoptic nor of high resolution".

Much has been written on the technical aspects of the errors associated with extraction of shoreline information from historical sources (Dolan et al., 1980, Crowell et al., 1991, Thieler and Danforth, 1994), the methods and limitations of image rectification (Dolan et al., 1978; Hoeke et al., 2001, Martínez del Pozo and Anfuso, 2008) and the various approaches to deduction of historical trends (Fenster et al., 1993, Smith and Zarillo, 1990). There are also issues around the selection of various indicators for shoreline change (Boak and Turner, 2005) and the relationships between them (Moore et al., 2006) and some of the problems of interpreting evidence contained in historical records are discussed elsewhere (Wood, this volume). The advent of image analysis software and Geographic Information Systems (GIS) has greatly facilitated the comparison of historical evidence from different types of source material by enabling

maps and air photographs to be reduced to a common scale and integrated with information from field surveys.

Associated changes in potential driving forces that might help explain observed shoreline changes are also variably distributed. Wave measurements are particularly sparse for most coasts of the world and even when they exist are of short duration and usually in deep water. They may undergo significant transformation before affecting the shoreline. Weather records (wind velocity, rainfall, temperature) and river discharge records can extend back several decades but their influence has to be interpreted in terms of the relationship of the recording station to the study area. Where actual measurements do not exist, or where it is necessary to gain a longer-term perspective than that afforded by existing records, proxies are sometimes sought. The nature of such proxies is variable according to the specific site but commonly-used proxies for past climate include the records contained in tree rings and speleothems. Climate indices based on long-term records of temperature gradients such as the North Atlantic Oscillation (NAO), El-Nino-southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO), often extend back more than a century and can be extended even further into the millennial record from geological evidence. When these indices bear a relationship to a climatic factor affecting a shoreline (usually wind or waves), they can aid the interpretation of past changes. Bryant (1985), for example, showed a relationship between the southern

oscillation, rainfall and shoreline behaviour on an Australian beach over an 85 year period and Rooney and Fletcher (2005) linked shoreline change in Hawaii to the PDO and storm intensity. Often, however, the relationship between such indices and climate variables, such as wind or storminess is not straightforward (Dawson et al., 2002).

At the century timescale, relative sea level change has the potential to exert an influence on shorelines, particularly if it is changing rapidly. The scale of relative sea-level change at century scale is seldom more than a few decimetres and its effects are difficult to discern from other higher magnitude, shorter term changes (e.g. Zhang et al., 2004). The effects of infrequent events, such as large storms (Morton et al., 2000) or tsunami (Gracia et al., 2006; Dawson and Stewart, 2007) can exert significant impacts on a coast at decadal to century timescales. The 2004 Indian Ocean tsunami, which is estimated to have a 500 year recurrence interval, caused shoreline retreat of >500m on several sandy coasts (Liew et al., 2008). The recovery of coasts after such events may take years or even decades and so it is important to factor such events into historical scale interpretations.

Inferences from observational records of high magnitude events can assist in the interpretation of historical records. In some instances, storms are simply part of the spectrum of shoreline process intensity (Fenster and Dolan, 1993) whereas in other instances they precipitate major departures from linear trends (Orford et al., 1999).

Other factors that may influence shoreline behaviour at long timescales include sediment supply from various sources (which can seldom be quantified), and human influences, whose nature can only be assessed by reference to written accounts, memory or anecdotal information.

The importance of considering an adequate temporal perspective is well illustrated by reference to analyses of the changing wave climate in the North Atlantic. Bacon and Carter (1991) identified an apparent increase in wave heights based on records from the Seven Stones Lightship in southern England between 1962 and 1986. This was believed to represent a long-term trend of increasing storminess. Subsequent research (Woolf et al., 2002, 2003) showed that the wave climate of that period closely followed a similar trend in the NAO. The fact that the NAO had undergone similar variations before suggested that the increasing wave trend was a secular rather than long-term trend (Jenkins et al., 2007). This has been borne out by a reduction in wave and wind energy since the mid 1990s which follows a reduction in NAO intensity.

The factors outlined above mean that assessment of decadal to century – scale changes and the potential reasons for such changes is not straightforward. It relies on amassing a diverse set of information of an interdisciplinary nature and using all the available evidence to make the best-reasoned explanation for those changes based upon knowledge from shorter-term studies that have higher levels of certainty on the relationship between forcing and shoreline

response. If subsequently, additional information becomes available, interpretations of long-term behaviour may change. Interpretation of long-term coastal change thus involves a combination of the two main cultures of investigation identified by Snow (1993): scientific/inductive on the one hand and literary/deductive on the other.

Case Studies

The case studies presented below are intended to illustrate the types of information used in historical shoreline change and the importance of a long-term perspective in setting short term observations in perspective.

They come from the KwaZulu-Natal coast of South Africa and the coast of Ireland. The South African examples are from a subtropical coast with a steep, weathered hinterland with abundant rivers and contemporary fluvial sediment supply while the Irish coast is paraglacial with a largely relict glacial sediment supply and limited contemporary sediment supply from the low, vegetated hinterland. Despite being located in different climatic regions, the sites share in common a high wave energy climate and a bedrock-framed coast with mobile sandy deposits forming headland-embayment cells in coastal re-entrants.

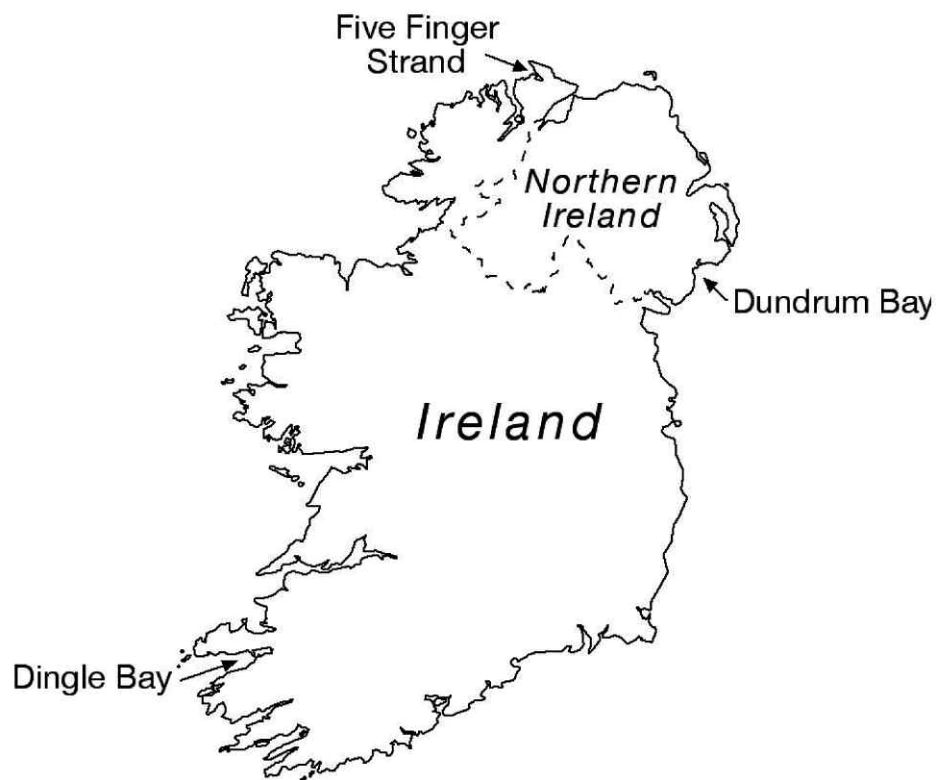


Figure 1 Locality map for sites in Ireland discussed in the text.

Inch Spit, Dingle Bay, SW Ireland

As part of a European-scale project into the impacts of climate change on the European Atlantic coast Orford et al. (1999) studied shoreline changes on a large sandy barrier system (Inch Strand) in Dingle Bay in southwest Ireland (Fig.1). This is a swash-aligned sand barrier situated in a deep bedrock embayment. Seabed surveys showed the nearshore zone to be devoid of modern sediment, suggesting the system to be in a mature stage of evolution with all available sand stored in the shoreface, beach and extensive vegetated dune system. Historical maps from 1834 and 1894, air photographs from 1949, 1967 and 1973 and field surveys of 1998 constituted the shoreline information base. From air photographs, the seaward limit of the vegetation line was mapped. The

same feature was mapped in the field using a Total Station. From the two historical maps, the High Water Mark was digitised. Thus 7 shoreline positions were identified. There is clearly a difference between the mapped HWM and the dune vegetation line, which was ascertained by field survey. Assuming conditions in the past to have been similar to today, an offset was applied to enable comparison between the mapped shoreline proxies from maps and those from air photographs.

Comparison of the shorelines showed a pattern of alternating advances and recession of the shoreline, particularly toward the distal end of the barrier (Fig.2). The records showed 1842 and 1967 to have been the periods of maximum recession, with more advanced shoreline positions recorded in

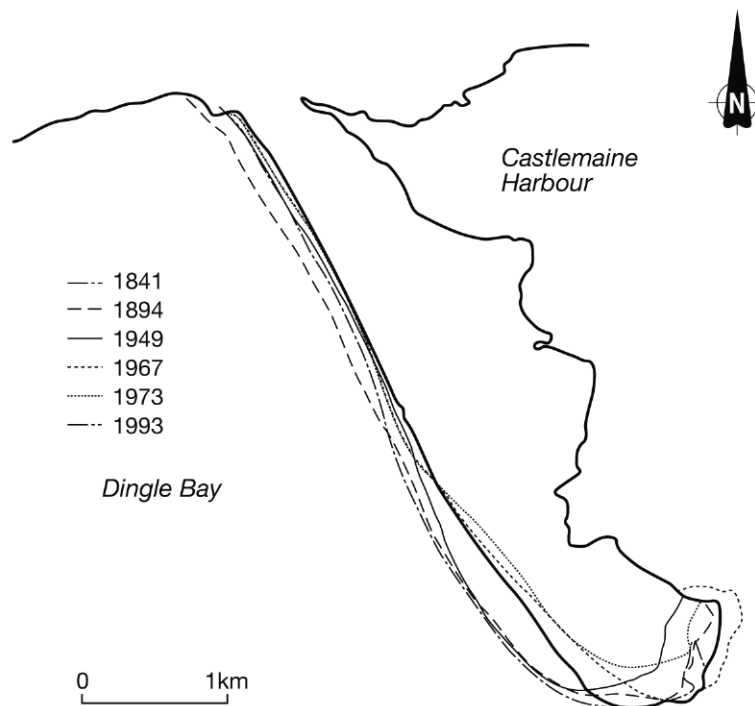


Figure 2 Shoreline changes on Inch Strand (after Orford et al., 1999).

intervening periods. Aerial photographs showed the more modern advance of the shoreline (post 1967) to be accompanied by foredune development and it was assumed that the earlier progradational phase (1842-1907) was accompanied by similar foredune development. To try and interpret the changes observed, analysis was undertaken of available climate records, sea-level change, surge potential and historical patterns of landuse. No clear link could be found that could adequately explain the observed changes, until extreme wind conditions were studied. This showed that the two highest magnitude storms of the period under consideration occurred in 1839 and 1961. The coincidence of these two periods with the records of maximum recession appeared to suggest a link between the two. Orford et al. (1999) interpreted the historical shoreline change as one of long-term stability

interrupted by these two exceptional storms (Fig.3). Reasoning that the beach was in a highly dissipative state and was modally attuned to the high energy conditions experienced on the Atlantic seaboard, Orford et al. (1999), argued that the energy necessary to cause shoreline recession was only available during such extreme events and associated with storm surges. Subsequent field visits after large storms (but smaller than these two extremes (in 1998 and 2002) showed no morphological impact on the foredunes, suggesting that the system is indeed able to cope with high energy waves during all but the most extreme storms. The timing of the two historical storms could also be compared with predicted tides and Orford et al. (1999) showed that both spanned the high tide period of tides close to spring tides. This combination, it was argued, is necessary to cause dune erosion.

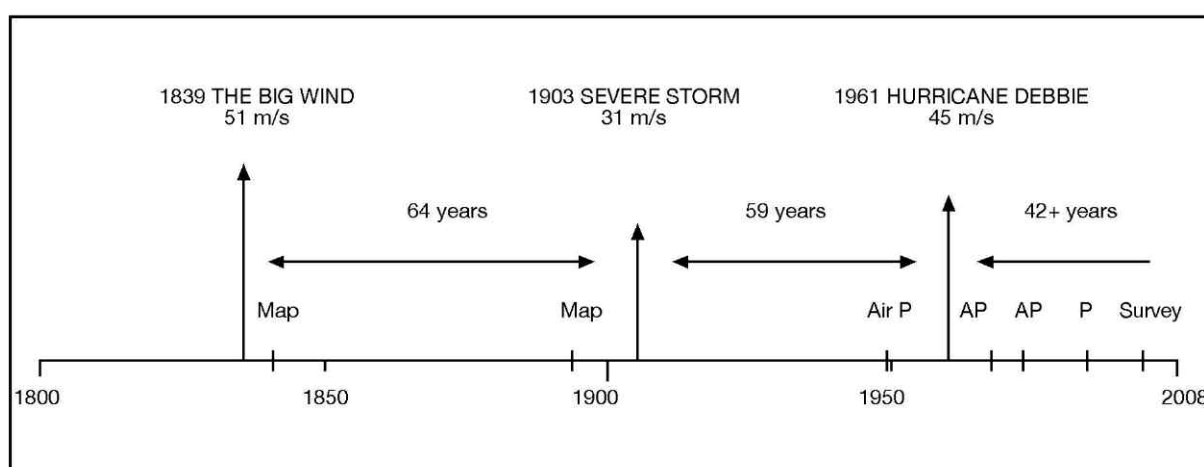


Figure 3 Schematic plot of the historical record of shoreline changes (AP= air photograph; P= photograph) with major storms and maximum wind speeds believed to be responsible for major shoreline recession (after Orford et al., 1997)

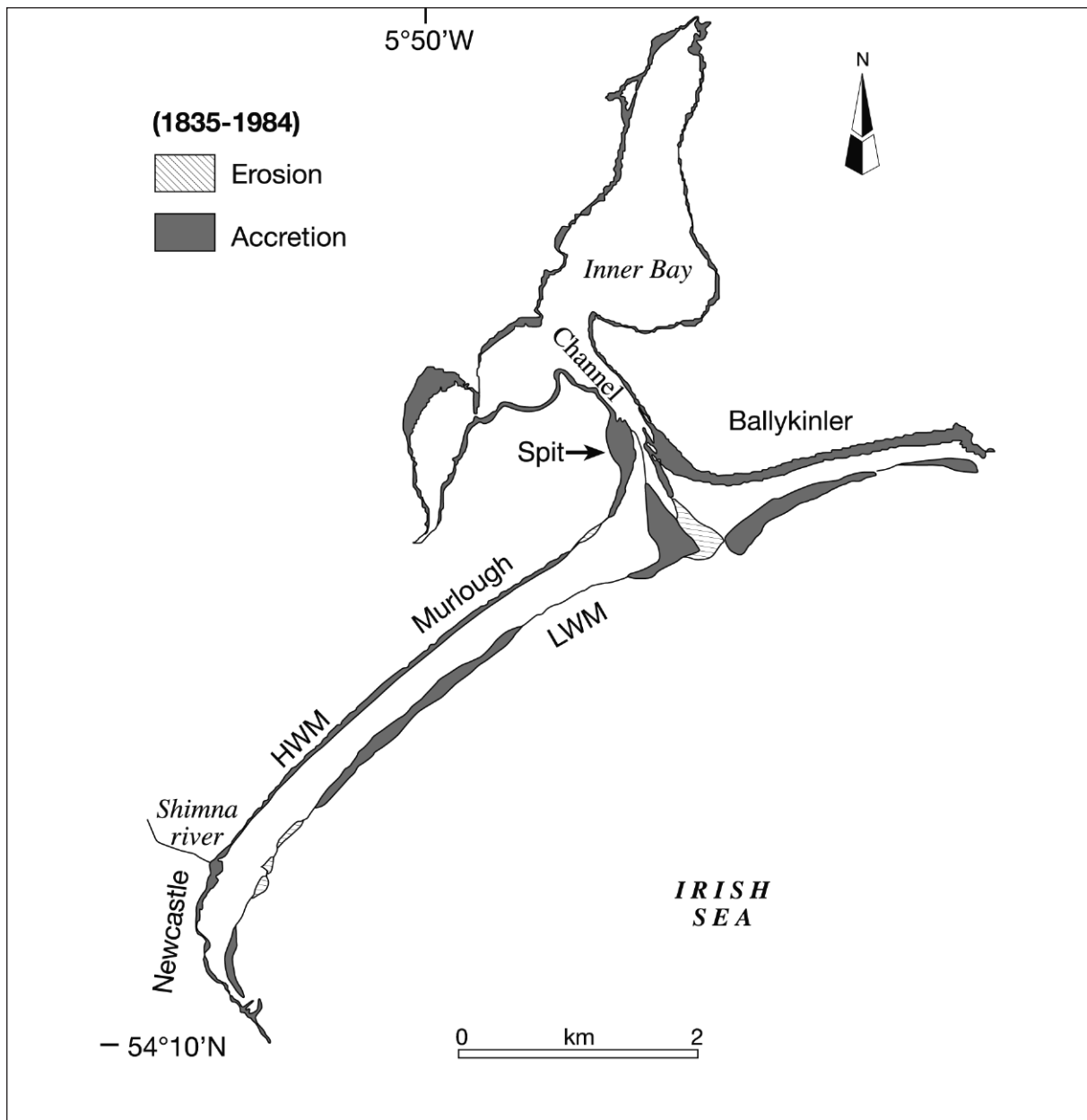


Figure 4 Net historical changes in Dundrum Bay shoreline 1835-1984.

Dundrum Bay, Northern Ireland

In Dundrum Bay, a large-scale macrotidal embayment on the SE coast of Northern Ireland (Fig.1), a sandy barrier topped by a wide vegetated dune field is present (Fig. 4). A tidal inlet in the middle of the bay provides a connection to a back-barrier lagoon. Historical patterns of shoreline change were identified from large-scale maps (1:10560, or 1:10,000) ranging in age from 1835 to 1984.

These were reduced to a common scale and the mapped High Water Mark (HWM) was digitized on the assumption that each survey would have employed the same criteria to delimit the HWM. The results showed progressive foredune accumulation in the northeast and beach lowering in the southwest (Cooper & Navas, 2004), suggesting a long-term sediment transfer in that direction with accompanying shoreline change. This pattern of shoreline change was

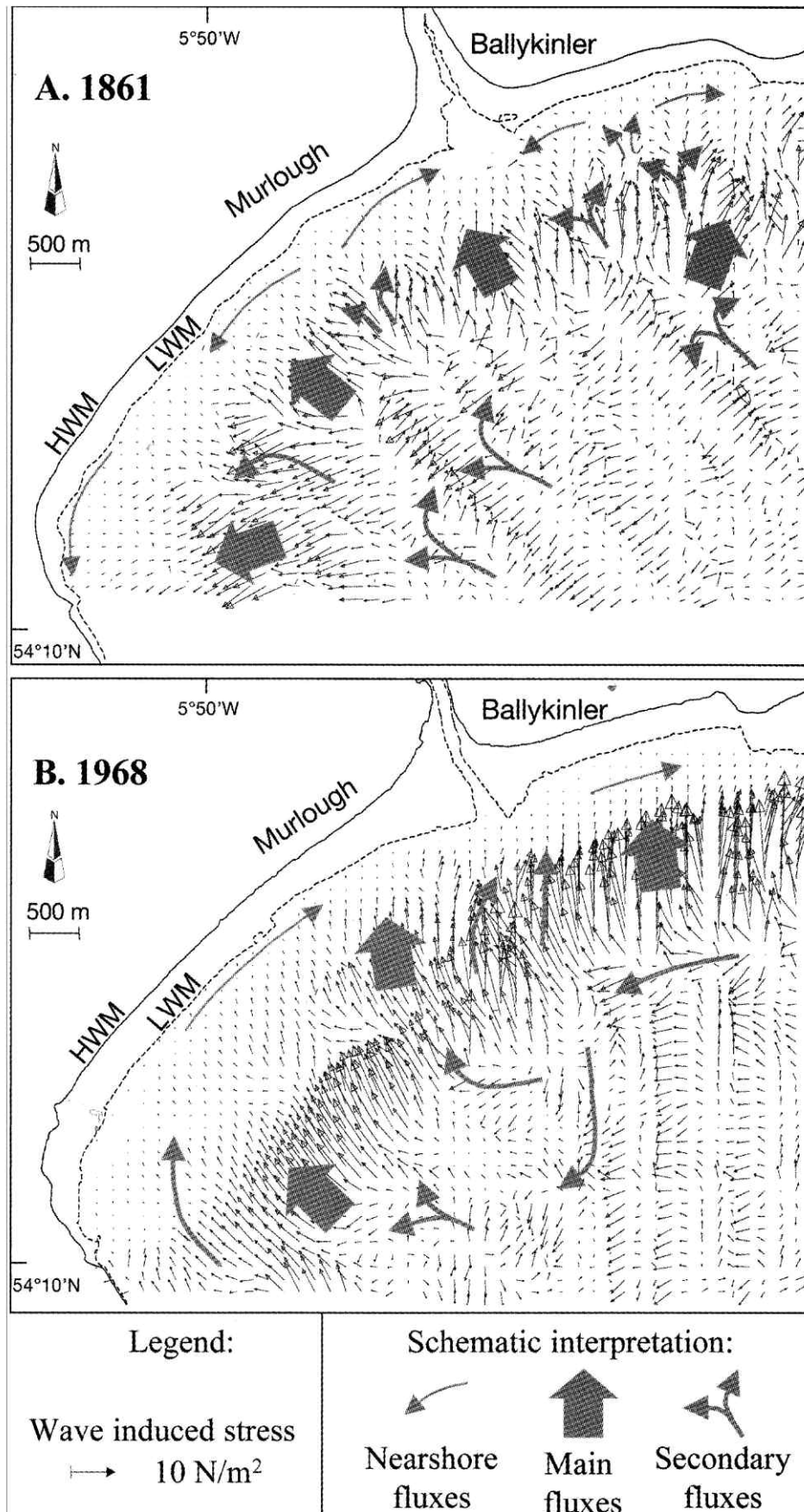


Figure 5 Simulated wave-induced sediment transport under mid 19th century and mid 20th century bathymetric conditions (after Cooper and Navas, 2004).

inconsistent with the overall morphology of the bay. At the millennial timescale Orford et al. (2003) showed that the entire shoreline had been advancing seaward through sediment accumulation during the past 6000 years. Examination of the sedimentary sequence showed that the Holocene dune system is underlain by gravel-armoured beach ridges that appear to accumulate at an approximately century timescale. The storm-induced armouring of the beachridges was interpreted as the result of the recurrence of an approximately 1:100 year event.

In an attempt to interpret the historical record of shoreline changes, Cooper and Navas (2004) analysed nearshore bathymetric records from the mid 19th and mid 20th centuries. Comparison of these showed the accumulation of a large sediment body on the inner shelf. Simulation of wave propagation over these two contrasting bathymetries (Fig.5) showed a change in alongshore transport direction at the coast with a drift divide in the mid bay and transfers to the NE and SW during the mid 19th century. Under the mid 20th century conditions, longshore drift was entirely toward the NE.

This identified change in drift direction during the 20th century was consistent with the observed historical changes in the bay (beach depletion in the SW and foredune accumulation in the NE) and the 19th century condition whereby sediment moving onshore is redistributed throughout the bay is consistent with the millennial scale evolution reported by Orford et al. (2004). The century scale observations of Cooper and Navas

(2004) might be linked to the pattern of beach ridge emplacement noted at millennial scales by Orford et al., (2004); the ridge emplacement at approximately 100 year intervals fits the timescale of bathymetric change and drift reversals suggested by the historical data. Although this is an attractive possibility, further research is necessary to test this hypothesis. The future implications of the observed historical changes are that barring any change in circumstance (for example, sediment supply depletion, sea-level change, or human interference), the pattern of shoreline change over the past several decades might switch to one of uniform accretion as the submerged sand wedge continues to move onshore.

Trawbreaga Bay, NW Ireland

A large beach and vegetated dune system is located adjacent to the tidal inlet of Trawbreaga Bay in northwest Ireland (Fig. 1). The shoreline on the beach (Five Finger Strand) has experienced rapid and dramatic erosion since the mid 1990s. The scarped face of the eroding vegetated dunes is over 20m high and 2km long (Fig. 6) and local concern over the erosion promoted a study of the possible causes (Cooper et al., 2007).

Historical sources included large-scale maps (1835 and 1900), air photographs of various scales (1952, 1977, 1995, 2000) oblique air photograph and ground photographs from the 1980s and field surveys from the mid 1990s. Analysis of this data set in conjunction with a local instrumental climate record and sea-level record extending back to 1955,



Figure 6 The eroding dune scarp at Five Finger Strand has retreated consistently between the mid 1990s and present (2008).

suggested that the shoreline on Five Finger strand had fluctuated significantly in parallel with the tidal inlet and associated ebb delta. Air photographs of 1977 and 2000 show the two extreme positions, both of which appear to have been taken at a 25-30 year timescale during the historical period. This conclusion was based on direct measurement of shoreline features and information regarding the inlet channel position inferred from maps that did not extend below the low water mark, but which nonetheless recorded the orientation of the intertidal section of the channel.

The morphodynamic significance of the two inlet channel positions is illustrated in Figure 7. When the inlet is located in a southerly position, a large seaward-convex

ebb delta developed in the southern part of the bay while the northern part experiences direct exchange of sand between the shoreface, beach and dune. Under such circumstances the dune accretes or remains stable. When the inlet switches to the north, sediment is drawn into a new delta in the northern part of the bay and the intertidal beach becomes lower as a result. Waves can then propagate to the base of the dune, causing erosion (Fig.7). At the same time, the southern ebb delta is abandoned and its sediment is reworked, but cannot cross the tidal channel to nourish the Five Finger Strand beach. Ultimately the channel switches back to its southerly position and the northern delta is reworked, supplying sediment to the beach once again.

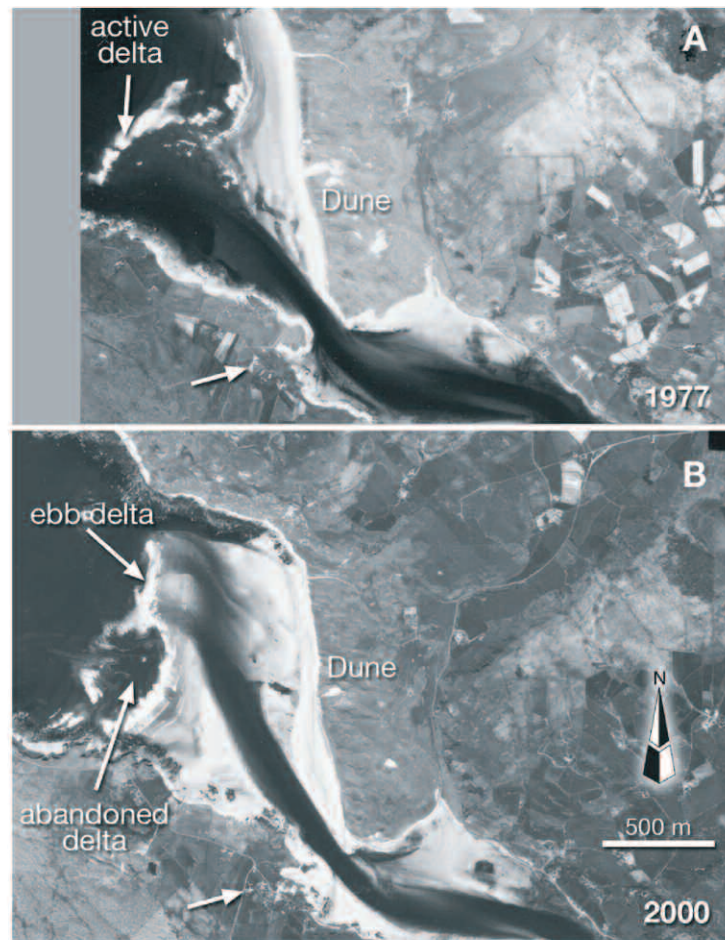


Figure 7 Historical evidence suggests that the tidal inlet at Trawbreaga Bay fluctuates between two extremes at multi-decadal timescales. The two extremes are shown in these photographs. Historical shoreline changes appear to be driven by inlet switches and formation of a new ebb delta and wave reworking of the abandoned one.



Figure 8 Locality Map, KwaZulu-Natal estuary barriers

KwaZulu-Natal barrier shorelines, South Africa

On the northeast coast of South Africa (Fig.8), historical analysis of shoreline changes on barrier systems at estuary mouths in KwaZulu-Natal was undertaken through comparison of the high water line as defined on air photographs by a tonal change between wet and dry sand. The coastline is microtidal and the beaches relatively steep so that the horizontal position of this line did not vary greatly with the stage of the tide. Changes at three such barriers are reported below.

At the Mgeni River mouth near Durban, based on the retreat of the dune line, the shoreline showed a consistent retreat between the first large-scale aerial photographs (1931) and field surveys of 1985 (Fig. 9A). All intervening air photographic records (1937, 1959, 1967, 1973, 1983) showed a consistent rate of retreat and at that timescale the

coastline was clearly undergoing progressive erosion (Cooper, 1993a). This was evidenced by outcropping of back-barrier mangrove muds on the foreshore and storm overwashing across the barrier and washover deposition into the mangrove swamp. Some concern was expressed at that time regarding the long-term prospects for the mangrove swamp (a nature conservation area) in the face of coastal erosion.

An extreme river flood (recurrence interval 120 years) in September 1987 (Cooper et al., 1990), however, eroded the rivermouth barrier and deposited a large volume of sediment on the shelf and shoreface, derived from the pre-existing barrier and fluvial bedload. Within six months wave action had transferred sediment from the submerged delta to the shoreface and rebuilt the barrier and adjacent beaches (Fig. 9B). In the three years after the flood the coastline continued to advance as more delta sediment was

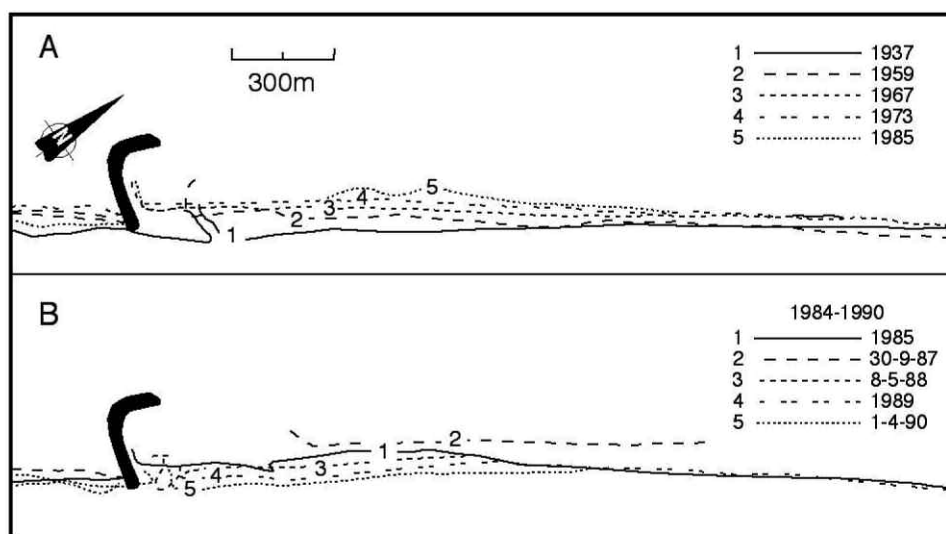


Figure 9 (A) Historical shoreline changes at the Mgeni Estuary barrier. (B) Post-1987 river-flood shoreline changes at the Mgeni Estuary barrier (after Cooper, 1993a).

transferred onshore and it attained a position similar to that of 1931 by 1990. Since then it has remained largely stable.

The changes wrought by the 1987 flood prompted a reassessment of the historical situation and searches of historical archives revealed that floods of similar magnitude had occurred in the Mgeni in 1917 and in 1856.

While there are no reliable records of shoreline position at those times, the 1931 photograph in which the shoreline is at its maximum seaward position is 14 years after the 1917 flood, suggesting that its advanced position at that time may have been linked to a similar influx of fluvial sediment as occurred in 1987. If so, this suggests that between floods, the coast is subject to slow, progressive erosion over periods lasting several decades, but that fresh injections of sediment during floods cause progradation

and a return to the initial conditions. Under such a scenario, the Mgeni shoreline is viewed not as eroding (as suggested by 1931-1985 records), but as stable in the long term with a long-term cyclicity driven by near-instantaneous deposition followed by slow, progressive erosion. This places the multi-decadal records of erosion in proper context.

The Mvoti estuary, some 80km north of the Mgeni, was similarly affected by extreme flooding in September 1987 (Cooper, 1993b). The entire barrier was eroded but post-1987 flood shoreline advance of 160m was recorded (Fig. 10). This was graphically recorded in a series of oblique air photographs which show the barrier destruction, emergence of a submerged post-flood delta and re-establishment of the barrier as the delta was reworked landward (Fig.11) over a three year period. This post-flood

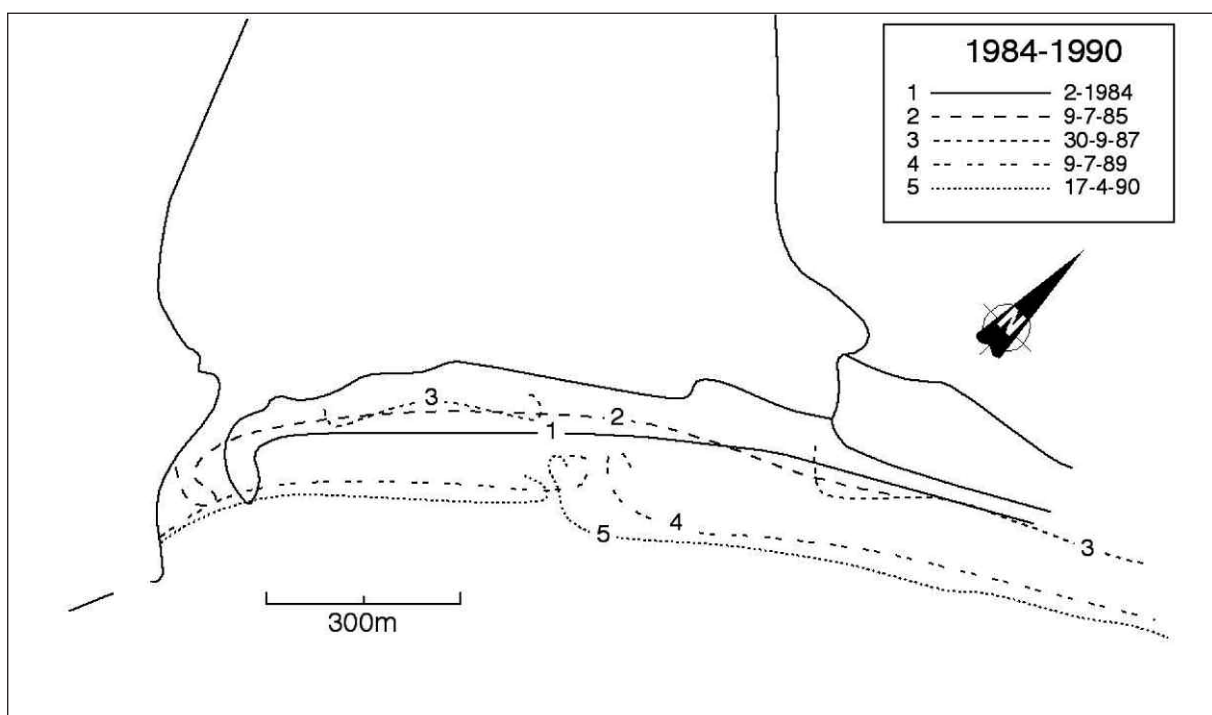


Figure 10 Post-flood barrier shoreline changes at Mvoti River mouth

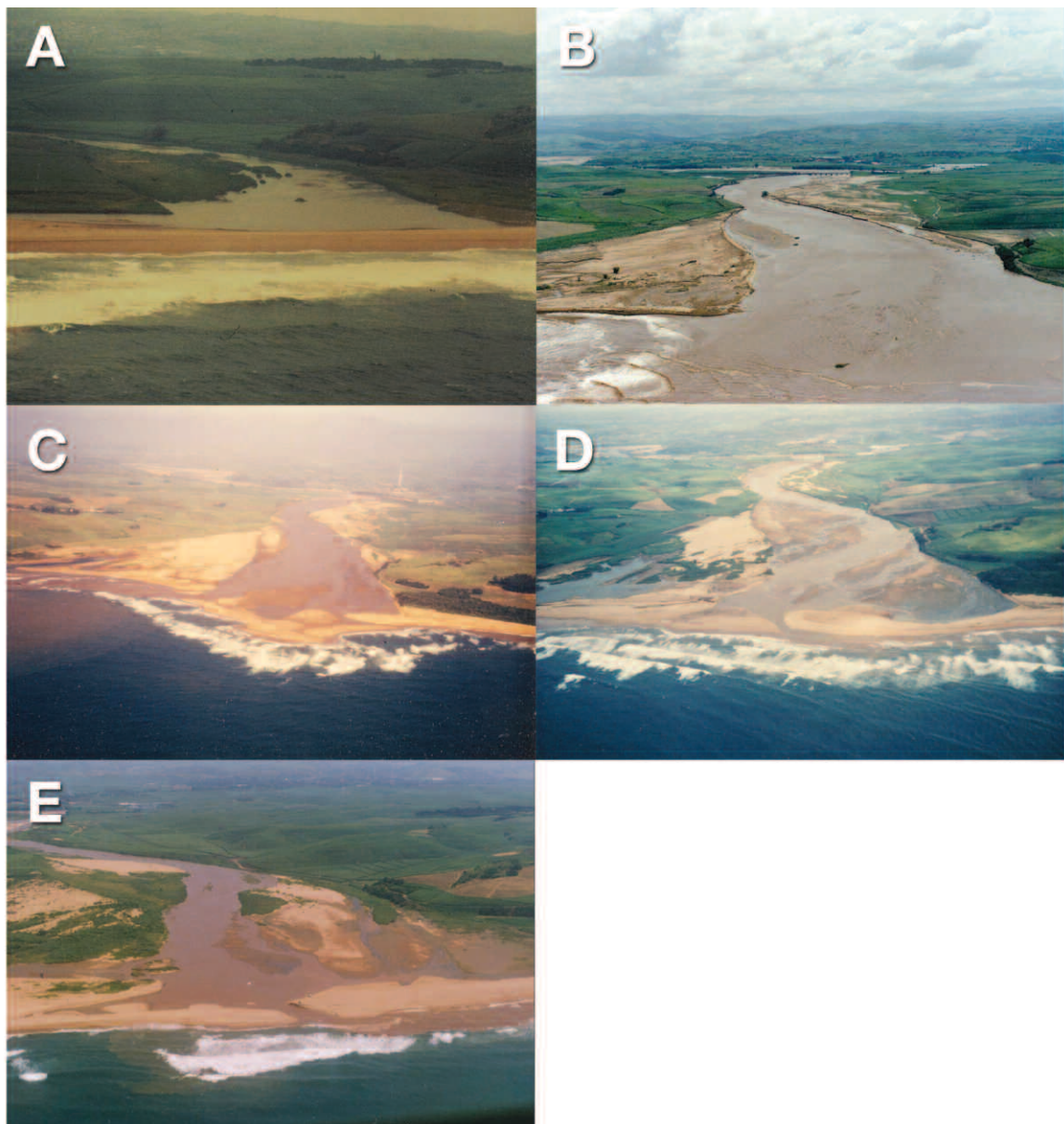


Figure 11 Sequential view of shoreline changes at the Mvoti Estuary barrier before, during and after the September 1987 floods. A. 1985, B. September 1987, C. October 1987, D. May, 1988, E. April 1990

shoreline advance contrasted with a long-term pattern of slow shoreline recession since 1937, suggesting that a similar pattern of coastal behaviour to the Mgeni was evident there.

The Mtamvuna estuary, 160km south of the Mgeni responded to the 1987 flood in a superficially similar way to the Mgeni and Mvoti in that its barrier and associated deposits (flood deltas) were completely

eroded (Fig.12). Post-flood barrier recovery involved landward reworking of the eroded barrier sands but unlike the Mgeni and Mvoti the post-flood barrier reformed in approximately the same position as its pre-flood equivalent. Thus the flood had relatively little impact on long-term shoreline behaviour, which is characterized by shoreline stability (Cooper, 1993c). The Mtamvuna differs from the Mgeni and Mvoti in being relatively immature in its

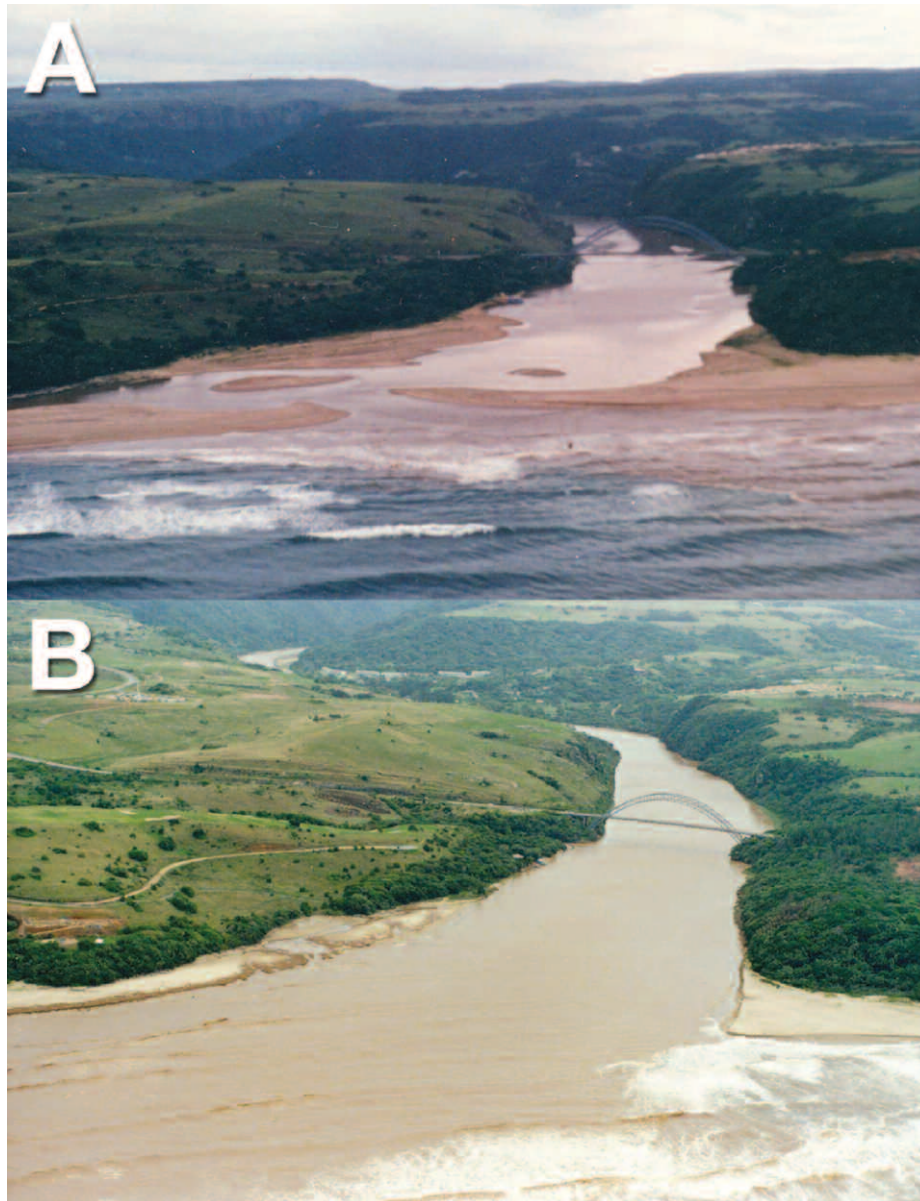


Figure 12 Fairweather (A) and flood morphology (B) of the Mtamvuna Estuary barrier. Complete erosion of the barrier and associated flood-tide delta results in deposition of an ephemeral delta in the nearshore. The delta comprises only sediment from the former barrier and tidal delta and when reworked, the shoreline position is similar to the pre-flood position.

evolutionary development (Cooper, 2002). It comprises a sandy barrier and tidal inlet with flood tidal deltas in its lower reaches, but has a deep, muddy middle reach and a fluvial delta at the head of the estuary. The mobility of the barrier-associated sand bodies ensured their rapid erosion during the river flood and deposition as an ephemeral delta (Cooper, 1990), but unlike the Mgeni and Mvoti, little

additional fluvial bedload sediment was deposited in the delta. Instead, any fluvial sediment was deposited upstream within the estuarine channel. Consequently, no additional sediment was added to the coast during the flood and the finite volume contained in the former barrier was simply reworked back to its former position.

Discussion

The examples above provide some case studies that illustrate the importance of taking an adequately long time perspective in interpreting shoreline changes in the context of coastal behaviour. They also illustrate the difficulty of making interpretations based on the fragmentary record of shoreline changes and associated driving forces. In each case the interpretation of long-term shoreline change and coastal behaviour is reasoned from the available evidence. While the above interpretations have withstood the peer-review process of international journals, any new evidence that may emerge of historical change or potential forcing mechanisms, may enable different interpretations to be reached. While this illustrates the need for long-term systematic data gathering of shoreline change, and of driving mechanisms (Stockdon et al., 2007), it is clearly unfeasible for every stretch of coast to be monitored at the desired resolution for interpretation of coastal behaviour, much less for wave, tide and climate data to be acquired at the ideal number of sites. A number of initiatives such as the coastal observatories in the UK (Mason, this volume) and formal shoreline monitoring programmes using new technologies such as airborne LIDAR at regular, shortly spaced intervals (e.g. Revell et al., 2002) offer the potential for the acquisition of long-term records in the future. Probably the longest existing records of shoreline change collected at high frequency are those of the Netherlands coast that have been surveyed regularly since 1963 (Wijnberg & Terwindt, 1995).

There are instances where the scale of decadal shoreline changes are similar to those associated with storms or seasonal variations (Guillen et al., 1999) and are indistinguishable, whereas in the examples discussed above, decadal to century behaviour is dominated by cycles of shoreline behaviour with long temporal periodicity. In the case of Dingle Bay and the KwaZulu-Natal estuaries, long-term cyclic behaviour appears to be driven by high-intensity, low-frequency events. In the Dingle Bay instance, only these events were capable of exceeding high morphodynamic thresholds to produce change in the shoreline indicator (the vegetation line) and subsequent recovery of the coast took place over a few decades. Measurement of coastal change during the recovery phase would have given the incorrect impression that the coast was prograding over the medium term. Instead, at century timescales the shoreline appears to be in equilibrium with ambient wave, wind and tide conditions, appears to have a finite sediment volume and is consequently stable. In the large Kwazulu-Natal estuaries (Mgeni and Mvoti), the periodic injection of fluvial sediment to the coast during extreme floods appears to replenish sand lost offshore or alongshore during several decades. Here too, a century-scale equilibrium appears to exist in which the shoreline retreats slowly over several decades but then advances rapidly after river floods.

The Dundrum Bay and Five Finger Strand sites show a different control on long-term cyclicity. In both cases self-organisation and morphodynamic feedback appear to be the

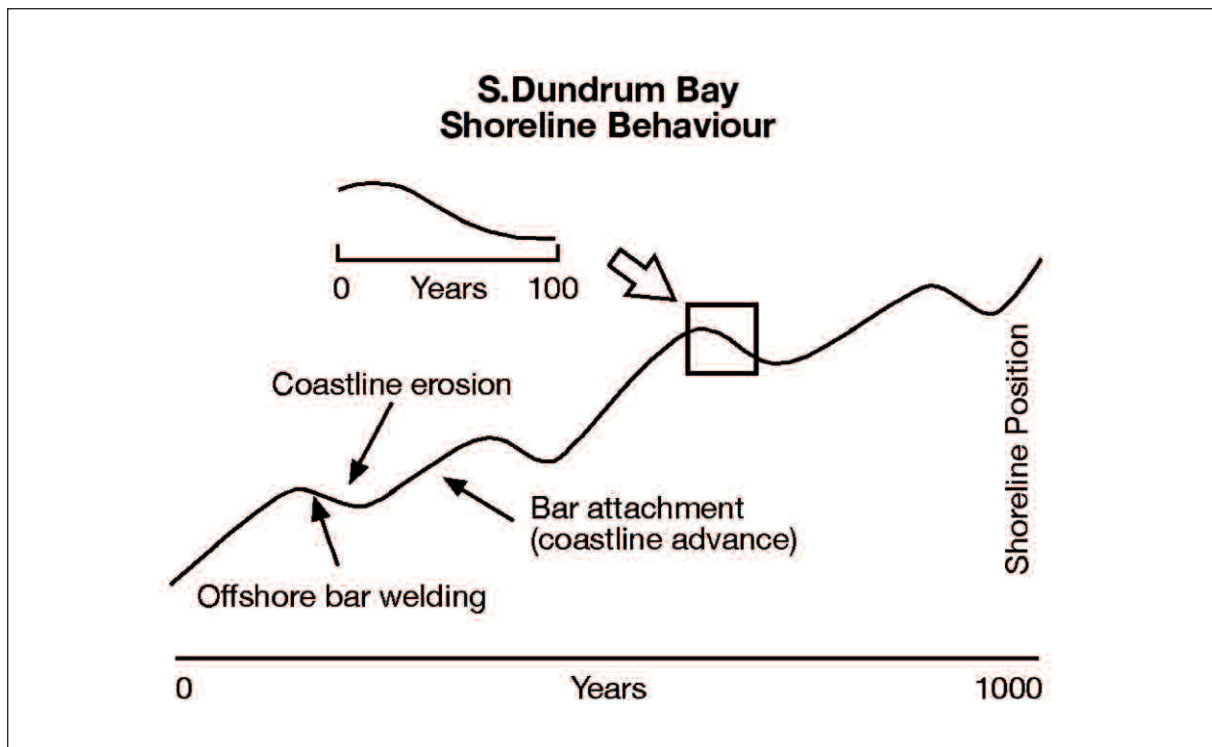


Figure 13 Conceptual model of shoreline behaviour in the southwest of Dundrum Bay (see Fig 4.) At the century scale the pattern is of shoreline retreat as longshore drift to the north moves existing sand from SW to NE. At the millennial scale, however, the onshore migration of sand from the shelf, increases the overall volume and alters the longshore drift such that fresh sediment is distributed to the SW and NE. Century-scale erosion is therefore envisaged as a temporary trend superimposed on millennial scale accretion

controls on century scale behaviour, rather than extreme events. At Five Finger Strand, seaward extension of the inlet channel occurs until (a) it becomes hydraulically inefficient and (b) remnant ebb-delta sand has been reworked, enabling the channel to switch position. The intervening periods of several decades are marked by what appears to be progressive erosion or accretion, but is really part of a longer-term behavioural pattern. At Dundrum Bay, progressive onshore migration of shelf sands alters the nearshore wave field as the plug of sand moves through. The longshore sediment transport pattern is altered and the distribution of sand on the shoreline changes in response. The model suggests that shoreline changes over several decades appear to move in one particular

direction but then reverse as the shelf sediment body welds to the beachface.

Conceptualising the long-term behaviour of these coastal systems enables their shoreline behaviour to be better understood. In Dundrum Bay (Fig. 13), erosion in the SW over a century is interpreted as simply one limb of a millennial scale behavioural pattern in which temporary erosion occurs due to wave modification as a plug of shelf sediment moves onshore. Once this sediment welds to the beachface, it is postulated that wave conditions change to disperse the new sediment to the SW and NE, causing overall progradation as has been recorded for the past several millennia. At Inch and Five Finger Strand (Fig.14), where a finite

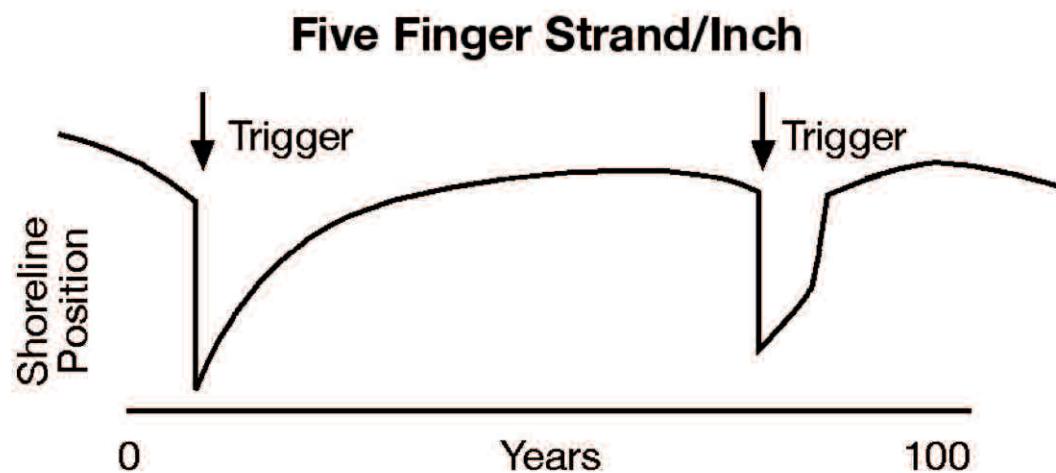


Figure 14 Conceptual behavioural model for Five Finger Strand and Inch Strand. The behaviour reflects a finite sediment volume in the beach and dune system that is stable in the long-term but which is periodically affected by an extreme event (in the case of Inch) or morphological adjustment by inlet switching (Five Finger Strand) that nearly instantaneously reduces the volume of sediment in the barrier. The eroded sediment remains in the system, either on the shoreface or ebb delta and in subsequent decades is reworked landward to restore the barrier volume.

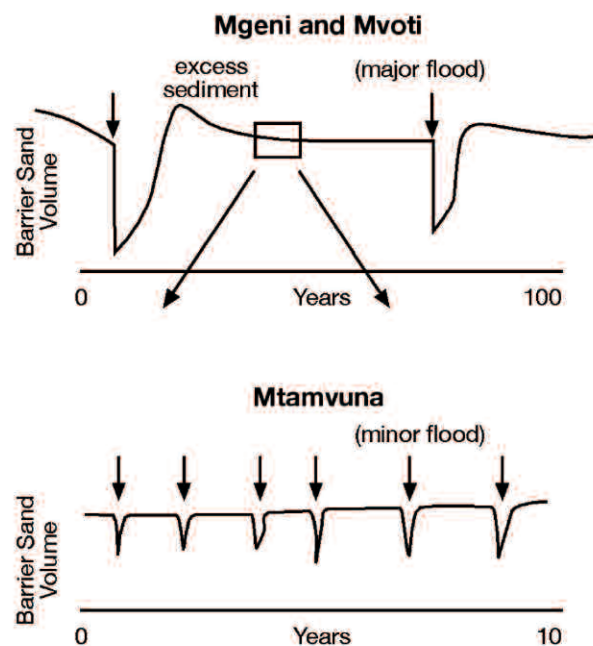


Figure 15 Conceptual shoreline behaviour model for Kwazulu-Natal estuary barriers. Large, mature estuaries like the Mgeni and Mvoti undergo major changes at century timescales as a result of major river floods. These erode the sandy barrier deposits, forming ephemeral submerged deltas. These deltas are augmented by fluvial bedload sediment and when they emerge under subsequent fair-weather conditions, have excess sediment. This is reworked alongshore and offshore by fair-weather waves over several decades giving the impression of long-term recession. A similar pattern of erosion of sandy barrier deposits also occurs at shorter time intervals, but in these instances, only the barrier sediment is eroded (it is not augmented by fluvial bedload) and the reformed barrier assumes a position similar to the pre-flood condition. The Mtamvuna characterises this type of behaviour.

sediment volume appears to exist, the systems show a long-term equilibrium that is punctuated by extreme storms (Inch) or inlet switching related to morphological adjustment (Five Finger Strand). In each case, the perturbation is followed by a recovery phase that may last several decades.

The KwaZulu-Natal estuary barriers (Fig. 15) show both short-term (Mtamvuna) and long-term (Mgeni and Mvoti) cycles of behaviour driven by episodic events. The periodic erosion of the sandy, barrier and associated deposits of the lower estuary can occur at timescales of a few years as exemplified by observations at the Mtamvuna. Under such circumstances, the erosion of the barrier leads to deposition of an ephemeral delta comprising the barrier sands. This is then reworked under post-storm conditions and the barrier reforms in approximately the pre-flood location. In the larger estuary barriers this same process occurs at regular intervals, but low frequency extreme floods not only erode the sandy barrier sediments, but also the estuarine channel and these, plus fluvial bedload are then deposited as an ephemeral delta. Post-flood reworking leads to the development of a barrier that has more volume than its pre-flood equivalent and consequently the shoreline advances seaward. Several decades of reworking under fairweather conditions are required to disperse the excess sediment and this is recorded as shoreline recession.

The examples above are from sites where the shoreline is relatively constrained in a longshore dimension, but both episodic

events and morphological feedback have been reported elsewhere at decadal to century scales on long, unconstrained sandy shorelines. On the barrier island chain of the Gulf of Mexico Morton et al. (1995), for example, showed the role of storms in transferring sediment across tidal inlets in Texas. This periodically caused rapid accretion on downdrift barrier islands. Ashton et al. (2001) presented a model of coastal evolution on long sandy coasts in which the trapping of small-scale cusped features by larger ones could lead to the formation of large scale shoreline features of kilometre-scale. Without such knowledge of the larger spatial pattern of change, incorrect assumptions would have been drawn regarding shoreline change patterns.

Conclusions

These case studies are limited in number and it is not intended that they be regarded as necessarily typical of long-term shoreline behaviour. Indeed, the cyclicity displayed in many of them contrasts strongly with the progressive shoreline recession that is dominant on many of the world's sandy coasts (Bird, 1985). The case studies do show, however, the importance of using an adequate timescale to properly understand the patterns of shoreline evolution and in particular the role of high energy, low frequency events in influencing shoreline behaviour for long periods. The paucity of data is a major hindrance to the analysis and interpretation of historical scale coastline change and consequently a wide range of sources and methods of analysis are required

for the most plausible interpretation. The combination of scientific/inductive and literary/deductive approaches involved, places this field of endeavour in what has been termed the “multicultural” domain (Snow 2003).

The main conclusions that can be drawn regarding the long-term patterns of shoreline behaviour are as follows:

1. Shoreline change observations are best understood in the context of coastal geomorphological behaviour on at least century timescales; extrapolation of linear rates of change may not reflect the true nature of coastal change. This is particularly true of shorelines where cyclicity in behaviour is anticipated.
2. Several potential factors contribute to the long-term behaviour of coasts. They include external forcing (e.g. high magnitude episodic events, the cumulative effect of low magnitude, high frequency events) and internal processes (self-organisation or self-adjustment). A sufficiently long timescale of investigation is necessary to recognise such changes.
3. The interpretation of past change is hampered by the incomplete nature of the historical record. To best understand historical scale changes, all available evidence must be assembled and interpreted as best as possible. Interpretations may change as more information becomes available.

4. Long-term monitoring is required to build up adequate datasets for interpretation of shoreline change and coastal behaviour at multi-decadal timescales. Although this requires a sustained commitment of resources that may bring little short-term benefit, it is necessary if some of the constraints imposed by the shortage of observational material are to be overcome in the future.
5. There is no simple model of shoreline behaviour that is uniformly applicable. The behaviour of any given shoreline is strongly influenced by its particular physical attributes as well as its exposure to temporally variable dynamics. Unpredictable and episodic weather events can exert significant instantaneous influence on shoreline behaviour that can influence shoreline behaviour for subsequent decades.

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